Can Brain Computer Interfaces Become Practical Assistive Devices in the Community?

Paul McCullagh[a], Melanie Ware[a], Maurice Mulvenna[a], Gaye Lightbody[a], Chris Nugent[a], Gerry McAllister[a], Eileen Thomson[b], Suzanne Martin[b], Stephen Matthews[b], David Todd[b], Vicente Cruz Medina[c], Sara Carro [c]

[a] *School of Computing and Mathematics, University of Ulster, United Kingdom*
[b] *The Cedar Foundation, Malcolm Sinclair House, 31 Ulsterville Avenue, BT9 7AS Belfast, UK*
[c] *Telefonica Investigacion y Desarrollo, Parque Tecnologico de Boecillo, 47151 Boecillo, Spain*

Abstract

A Brain Computer Interface (BCI) provides direct communication from the brain to a computer or electronic device. In order for BCIs to become practical assistive devices it is necessary to develop robust systems, which can be used outside of the laboratory. This paper appraises the technical challenges, and outlines the design of an intuitive user interface, which can be used for smart device control and entertainment applications, of specific interest to users. We adopted a user-centred approach, surveying two groups of participants: fifteen volunteers who could use BCI as an additional technology and six users with complex communication and assistive technology needs. Interaction is based on a four way choice, parsing a hierarchical menu structure which allows selection of room location and then device (e.g. light, television) within a smart home. The interface promotes ease of use which aim to improve the BCI communication rate.

Keywords: *Assistive technology, brain-computer interface, user centred design, graphical user interface*

Introduction

Communication and control of the environment is vital to everyday life. In many cases disabled people have gone to extraordinary lengths to communicate. Consider the memoir of Jean-Dominique Baub (Diving Bell and the Butterfly; Le scaphandre et le papillon [1]), which depicts Bauby's life after suffering a massive stroke that left him with amyotrophic lateral sclerosis (ALS) or 'locked-in syndrome'. Bauby developed a system of communication with his speech therapist by blinking his left eye as she read a list of letters to spell out the text and completed his book. Scott Mackler, a neuroscientist in the Veterans Administration Medical Center, also succumbed to ALS and is completely paralyzed, retaining only eye movements. He now communicates through a Brain Computer Interface (BCI), which has led public awareness of the technology (CBS news 60 minutes documentary [2]).

In 2002, Wolpaw et al. [4] offered the following vision: "BCI systems could eventually provide an important new communication and control option for those with motor disabilities and might also give those without disabilities a supplementary control channel or a control channel useful in special circumstances". Allison updated on the prospects of BCI in a 2007 review [5], stating: "BCI systems have just begun to provide significant assistive communication technology to people without other effective means of communication in their home environments." BCI could also be applied in applications where existing communication is desirable, e.g. noisy industrial applications, or as a gaming or entertainment interface [3].

A BCI provides communication from the brain to a computer or electronic device. Communication is achieved by collecting the subject's brain waves, known as the electroencephalogram (EEG), and then translating some information contained within these signals. Currently the information that can be obtained from the EEG is quite limited, as the EEG is inherently noisy containing endogenous and exogenous components, relating to sensory, motor and cognitive activity in the brain. Certain motor and sensory EEG components may be induced or enhanced, revealing the person's intentions when performing some activity, for example moving a cursor on a monitor, in order to control an application. This is potentially powerful when combined with interaction and control of a smart environment [6].

There are three main paradigms: the 'odd ball' paradigm to elicit an event related response (known as the P300 response) from the EEG; an 'imagined' movement paradigm; and the steady state visual evoked potential (SSVEP),. The P300 is a positive exogenous potential which occurs approximately 300mec after a 'rare' or unexpected auditory, visual or somatosensory stimulus and can be used to infer a subject's attention to the stimulus. It requires the average of a number of stimuli to enhance the signal to noise ratio. A component in the motor area of the brain (known as event related synchronization or mu rhythm) can be used to determine if the person is ‘imagining’ that they are moving, for example, their left or right hand. SSVEP requires an external visual stimulus to evoke a steady oscillatory component in the EEG, at the same dominant frequency as the stimulus. It is primarily located at the occipital region of the brain. A summary description of these paradigms and possible disadvantages are listed in Table 1. In each case the EEG must be analysed to produce distinct classifications which can be used to navigate an interface, and hence potentially interact with the environment. Misclassification of EEG, of course, results in errors in interface control.

Table 1: Comparison of BCI paradigms

BCI paradigm	**Description**	**Disadvantages**
P300	Stimulus: The Bremen ‘speller’ uses 6 flashing rows and 6 flashing columns to cover the alphabet and numbers. A number of repeat flashes are performed for the rows and the columns. The evoked potentials are extracted from the EEG for the rows and the columns. Then the classifier uses the row and column to determine the value.	It requires concentration by the user on the screen. The user may become distracted or focus on a wrong symbol/tile. Approximately 16 repetitions are needed to determine the class, due to the small signal to noise ratio. Over familiarization can lower the P300 response.
Imagery	No Stimulus: Imaging the movement of: right hand, left hand, right foot, left foot enhances motor potentials in the brain. Many researchers consider this the ‘purest’ BCI as there is no external input required	Imagery requires significant training of the user. It also requires concentration. The user has to relate a certain imagined movement to a particular decision. They could easily make a mistake in this process.
SSVEP	Stimulus: A tile or symbol flashes at a defined rate (8-50Hz). Decisions are dependent on the number of stimulating frequencies being used. (Usually between 4 and 10).	It requires concentration by the user as they need to look at the correct flashing tile. It is tiring and suffer5s from possible habituation effects.

The recording of these components for use in a BCI has many challenges. An individual may be better suited to one of these approaches or may be completely BCI illiterate. The recording parameters (electrode location, spatial filters) also need to be ‘personalised’ to the individual and may be affected by ambient conditions, environment, habituation and fatigue. For people with complex problems the situation is obviously more difficult due to brain injury, additional movement artefacts and reduced periods of concentration. However already, spelling devices can be used to enable those without means of communication to ‘voice’ their thoughts, by linking to a speech synthesizer.

BCIs are difficult to set up. For example recording constrains the user to be close to an amplifier, requires different approaches, and lacks recognised standards. Placing electrodes on the scalp can be arduous and unpleasant to the user, and requires expertise by an assistant. The equipment comprising electrodes, cap, amplifier, computer and stimulus device is expensive and is not aesthetically appealing. Furthermore, solutions hitherto have been geared towards technical demonstrations to showcase scientific advances without specifically focusing on the needs of the users. However for inclusion in society, a BCI could have a major impact, particularly for those with severe physical disabilities. For the small number with ALS, it may be the only technology that could achieve this.

BCIs with Rapid Automated Interfaces for Nonexperts (BRAIN, [7]) funded by the European Commission’s Framework 7 programme, addresses the accessibility of BCIs. In order for BCIs to become practical assistive devices it is necessary to take BCIs into the community. In particular; to make BCIs accessible to a non technical user and their care giver and to ensure that operation is sufficiently robust so that constant intervention is not a requirement. By doing this the BRAIN project intends to make the performance of day to day activities accessible to users for whom this has not previously been the case, thereby promoting the social inclusion of those most in need.

In this paper, we report on the design of generic interfaces [8, 9] for the user, built upon an architecture that will allow a wider variety of applications to be supported. Two threads of development exist. The first is the interface that the user sees and interacts with. Secondly, there is a range of possible applications that could be included and will need to be handled within the same BCI system. For example, enabling BCI control of the television, a music player, a speller; or control over assistive devices within a smart environment.

This is an example of pervasive computing, an emerging research area where sensors and computers support people in their home environments. In these environments, it is highly desirable that the systems and services must be able to adapt and react without the need for people to intervene to configure them.

Methods

BCIs have benefited from improved sensors, smaller amplifiers, better signal processing techniques and a move towards standardization of interfaces. However, it is important that research is focused upon applications that the potential user groups actually want, so the design methodology is to allow users to influence the development. There are two groups: users with complex communication needs and users who may use a BCI as technology of choice for work or entertainment.

User Surveys

BRAIN has adopted a user-centred design approach, involving 2 separate groups of participants in two countries. The user study comprised quantitative and qualitative techniques. In Northern Ireland (United Kingdom), the Cedar Foundation convened workshops and surveyed the needs of six tenants of sheltered smart housing. They expressed an appreciation of the value of the BCI system and a sense of satisfaction of being involved in the development process. One participant was unsure if they would use the technology, but the others were keen to try it. A total of fifteen people participated in the user sessions at a Telefonica site in Spain. The qualitative research was conducted by focus groups, of 8 and 7 participants each and the quantitative part was gathered from surveys delivered to users. The results of the user survey (see below) influenced the design of the user interface, and the target applications.

Interfaces

Interface design is key to uptake of technology, and this is particularly important for BCI, which suffers from a slow communication bit rate. There are three interfaces: (1) An electrical interface via electrodes and amplifiers, which collects EEG from the user; (2) A Graphical User Interface (GUI) which provides feedback to the user regarding the state of the application; and (3) An Application Interface, which provides actuation from the computer to the environment. It is important that a number of applications can be controlled and thus we aim to produce a Universal Application Interface (UAI). The BCI comprises software for paradigm control, signal processing and feature extraction (called BCI2000, Schalk [10]), GUI and UAI, with drivers appropriate to different domotic devices. The user views a GUI and dependent upon the paradigm (SSVEP, P300 but not imagined movement) will view stimuli, presented via external light emitting diodes (LEDs) or on a computer screen.

A number of BCI user interfaces have been reported. These include: the 'Hex-o-Spell' mental typewriter [11], BCI2000 implementations [10], an SSVEP speller [12] and Milan's Adaptive Brain Interface [13]. The current GUI is influenced by the SSVEP work of Piccini [14], and has been adapted to higher frequency LED stimulation [15]. The GUI consists of two modules:

- Display Requirements Module, which adapts the graphical interface to limitations, imposed by the BCI protocol and user preferences.
- Device Interface, which handles the interface between the GUI and the BCI2000-based BCI system.

The BCI system performs signal acquisition and processing, resulting in events that the GUI is able to map to actions of the UAI applications. During operation, BCI2000 stores data, along with event markers and information about system configuration. Additional signal processing routines (written in Matlab) provide classification into four categories (right, left, up, down). Communication between the various modules is by classified user datagram protocol (UDP) packets over a socket connection. The GUI menu structure is defined in extensible markup language (xml), which facilitates the declaration and description of structured classifications. In this manner a menu hierarchy is defined and menu icons associated with appropriate commands. By using xml in this manner the GUI becomes a menu parsing facility. This makes it possible to harness the interface for many different purposes or to facilitate the tailoring of the interface according to individual user needs. The GUI provides the user with navigation through various locations in the smart home. In Figure 1, the menu indicates current location as the "back garden". The down arrow can then select 'controllable' smart devices in this location.

Figure 1: IGUI showing high level location menu within the Smart home

If for example, a room was selected then devices within the room that the user could operate become available. For example, Figure 2 shows the current state of the door. This 'device' can be toggled by selecting 'down', i.e. if the door is currently 'open', it will be closed by actuators associated with UAI.

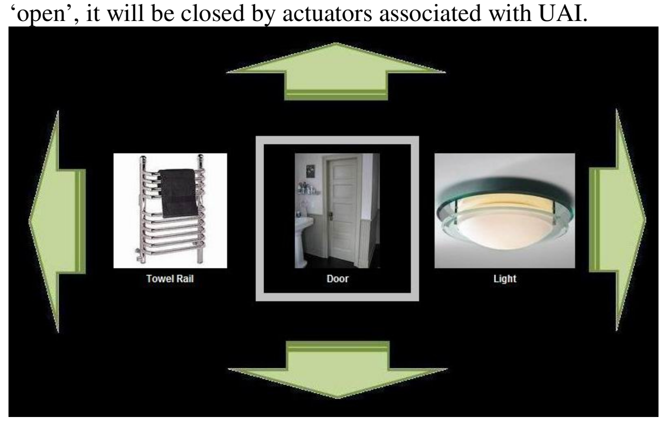

Figure 2: IGUI showing activation of the door open/close (within a room/location)

Results

From the CEDAR workshop and the questionnaire, user requirements were obtained. In terms of physical requirements, all CEDAR participants are wheelchair users with a range of seating postures and positions. It is important therefore to establish the acceptable working distance of the individual when wearing the BCI cap, in relation to device that will house the system. All participants required significant assistance from care staff for activities of daily living. For BCI, assistance will be required to fit the cap and electrodes. A practical requirement is the importance of training and support, for participants.

In terms of user preferences, communication is the prime function users wish to try, although using the system to support phone calls was not well received. Accessing multimedia content is of interest. Television is the most important entertainment device to participants, and integration of the BCI software into the television or vice versa may support access and usage.

From the Telefonica workshops and questionnaire (N=15; 10 male; 5 female, 21-52 years old) further user requirements were obtained which pertain more towards BCI as an additional technology. Time spent at home was dominated by watching television (TV: 3 hours, Internet: 2.5 hours; work/study: 2 hours; phone communication 2 hours; housework: 1 hour; other: 1 hour).

Requirements for Automation Control: (Video:13 users/ 15; Heating:13; Audio:12; Security:5; Doors:3; Lights:2;). The main concerns of automation systems within the home environment included high prices, the early stage of the technology, reliability and maintenance, security and the new infrastructures (i.e. need for wiring).

Requirements for Multimedia devices (TV:15 users / 15; PC:15; Mobile Phone : 15; DVD: 11; Tuner:6; others:3). The users expressed desire for an entertainment system which can manage multimedia formats, and whose content can be stored in any media server in the home network. Interoperable systems are desired. The system should support the control of many devices, from media players and servers, to domotic devices/sensors, and communication devices, all coming from different technologies. In case of people who need special care, this is considered essential. The television is one of the most valued devices to be controlled by BCI system. The context environmental information should be taken into account to handle smart services.

The BCI system is considered by users as a possible 'remote control' to access to home applications. For a skilled BCI user, this could be a simple task. Techniques to make training easy are requested. The majority remarked that improvements of graphical interfaces are needed to make them more usable. This work has influenced the design of the Graphical User Interface (GUI). The GUI should be implemented on a multimedia workstation which could also function as a television and communication device.

Software and Hardware Testing

Testing has been carried out to ensure that the GUI can interact with the BCI recording system and the domotic applications. Extensive unit testing of menu operation and the ability to issue a command has been completed. Integration testing of the GUI has been successful concerning:

- Demonstration of the correct traversal of the GUI menu via mouse operation. This offers a good test environment and provides the facility for a care giver to operate the GUI should the user require additional assistance. For instance GUI shut down, should the user become tired.
- Demonstration that the GUI will successfully receive and unpack BCI2000 generated, UDP Package content, thereby providing the user with a mechanism to traverse the GUI menu structure via BCI.
- Demonstration that the GUI can issue commands to the UAI which are received and invoked. Commands are invoked as a web service offering the potential for remote control where necessary.

A television (TV) control application has been completed, which allows the user to control the most used functions of a TV set: power on/off, change channel, change volume. A TV set that natively supports the required universal plug and play (UPnP) functionality does not exist in the market place. Most Digital Living Network Alliance (DLNA) compliant TVs are limited to browsing and playing the content found in the Media Servers connected to the home network. However, set top boxes exist that provide remote control features through the ethernet port, e.g. Dreambox 7025 TV tuner (https://www.dream-multimedia-tv.de/en/dm-7025), which allows streaming, electronic program guide retrieval, and schedule of recordings. When the TV input is connected to the Dreambox, the channel displayed and the volume can be controlled from the UAI. A UPnP light emulator was implemented for integration testing. Initial supported devices include UPnP PowerSwitch service and wireless X10 controller. New devices are supported by means of a UPnP wrapper around the native application programming interface (API) of the device.

Initial testing with subjects indicates that the high frequency SSVEP paradigm is feasible in the research laboratory. However, it is necessary to calibrate frequencies for each subject under test and work is underway on a software wizard to facilitate and expedite this process. At present, interface metrics regarding usability in the two target groups still have to be collected.

Discussion and Conclusions

The User Interface uses a 4 way interaction: left, right, up, down. Currently menu items are grouped by space and function in order to ease identification and selection. These groupings can be adjusted within the xml declaration in order to balance depth and breadth of navigation, to facilitate the accessibility of final commands by reducing the number of menu navigation steps required to reach them. Primary grouping is made by the rooms associated with the users' housing environment: living room, bedroom, hall etc. and then by function: lighting, television, heating. An additional classification of menu item 'Sticky' is used to ensure that significant applications such as a Speller, or the ability to answer the door or phone are always available. The environment to deploy UAI applications as web services has been set up under the Equinox OSGi framework. UAI applications are implemented as OSGi bundles that are easily installed in the system. The UAI is able to filter the discovered UPnP devices so that only authorized devices are operated. The software light emulator and light control application has been successfully tested, and indicate the potential for more complex domotic device interaction. Additional user trials will allow us to collect information which can then be used to impart intelligence into the menu structure. This can improve the effective bit rate of the BCI.

The Graphical User Interface is intuitive and can be personalized. The menu is based on photographs of the intended location/device, which may be personalized to the specific environment, and so should be intuitive in use. It does not rely on literacy. The size of the menu could be scaled, appropriate to poor visual acuity. The menu structure may be easily extended for further rooms/devices. Each device can have additional menus appropriate to the complexity of operation, e.g. a media player will have more controls than a simple switch. Interaction with the UAI is via web services, and a queue of current events. GUI and devices can communicate with this queue to indicate their current state, e.g. turn a light off, if already on. Communication with the BCI is via UDP network packets. This provides a decoupling of technologies, enabling independent development (e.g. BCI200 has been developed in C++, whereas the IGUI has been developed in JAVA). This provides an IGUI which is potentially open to the wider community for enhancement.

In conclusion, we are in the process of implementing a BCI system designed to be used in the community. Paradoxically initial testing has occurred in a controlled setting, and hence our overall rationale still requires validation. However, we believe that the approach allows us to deploy a system to deliver a number of services, which the users desire, with familiar control using a consistent extendable (and in the future) context aware intelligent GUI. These advances are necessary for BCI to become practical assistive devices, but are not sufficient, and we need further progress in electrodes, caps, signal processing, convenient set-up and detailed understanding of user interaction with the system.

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Address for correspondence

Dr PJ McCullagh

School of Computing and Mathematics

University of Ulster at Jordanstown

Shore Road, Newtownabbey, Co. Antrim

BT37 0QB, Northern Ireland